SPECTRAL CHANGE BASED OPTICAL SENSORS

Josef Eliáš

Doctoral Degree Program (2), FEEC BUT

E-mail: xelias10@vutbr.cz

Supervised by: František Urban

E-mail: urban@feec.vutbr.cz

Abstract: This paper is focused on optical sensors based on spectral characteristics change. Optical sensors are widely used for industrial, robust and noise proof measurement. There are measurement techniques for mechanical tension, temperature, pressure, displacement, vibration and so on. This article provides brief description of selected optical sensors based on Fabry-Perot and fiber Bragg grating principle. The article includes basic sensor description, theory of operation and measurement setup and expected measurement ranges and resolutions.

Keywords: Fiber optic sensors, Fabry-Perot interferometer, Fiber Bragg Grating, Measurement.

1 INTRODUCTION

Harsh environment and optical telecommunication industry, initiated development of fiber measurement and sensors. Nowadays there are hundred principles how to measure sensor response up to 80 kilometers using Fiber Bragg Gratings (FBG) based sensors[1]. There are sensors for measuring temperature for many different ranges. First range widely used in power industry is ambient temperature[2], high temperature[3] and also cryogenic temperature[4]. There are strain measurement sensors based on FBG's [5]. Strain and temperature measurements can be transformed into high voltage measurement or current measurement. Another indirect measurement is inclinometric and acceleration sensors transducing gravity acceleration into mechanical strain.

2 STRAIN MEASUREMENT

Strain measurement is one of two direct measurement based on displacement of periodic structure inscribed into fiber. This mechanical stress is converted into central reflected wavelength shift of FBG[6]. Central wavelength shift dependence of FBG is characterized by equation (1). In this equation there are two main effects influencing central wavelength position reflected from FBG. One of them leads to strain and other to temperature dependency of sensor. There are several methods to avoid temperature dependency of strain sensors. One method use compensation grating and differential central wavelength change, others are based on prestrained fiber bonded to composite material with balanced dimension expansion to 0. Basic strain sensibility of FBG type I and II ranges from 1.10 to 1.19 but according to

$$\frac{\Delta\lambda}{\lambda_0} = k * \epsilon + \alpha_\delta * \Delta T \tag{1}$$

$\Delta\lambda$ = wavelength shift
λ_0= base wavelengthat at test start
k = gage factor ~ 0.78
ϵ = strain
ΔT = temperature change in K
α_δ = refraction index change

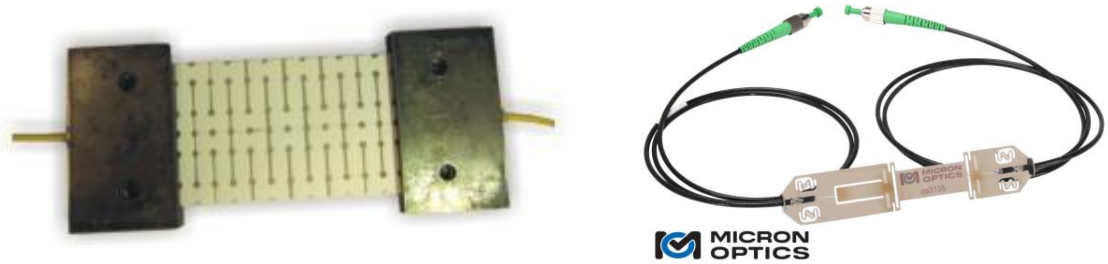

Figure 1: Surface **s**train sensors [7] [8]

Basic strain sensors can be found on Figure 1 [8]. These sensors are designed for industrial use and can be chained into sensor field along bridges, dams, roofs, tunnels or into towers. NASA introduced multipoint real time measurement for shape deformation sensing in real time called FOSS [9].

3 TEMPERATURE SENSORS

Temperature dependency described in previous paragraph can be used in temperature sensors. These sensors can be used for precise single point measurement or as multipoint measurement array. Sensors are lightweight as standard telecommunication fiber and sustains high temperatures as 100 °C. For higher temperature measurement there are special FBG's made by micromachine inscribing process. Micromachined fiber sensors cannot be erased by high temperature like standard FBG and therefore these sensors are only limited by melting point of pure silica. According to our measurement uncoated FBG has temperature dependency about 10 pm/°C. Like strain sensors, temperature sensors can be chained into arrays and perform multipoint measurements. Temperature sensors finds use in oil and gas industry for monitoring infrastructure and condition. Classic temperature sensor with FBG inside are shown on Figure 2. These packages are similar to classic PT thermocouple sensors used industrial.

Figure 2: Temperature sensors and probes [7][8]

4 HIGH VOLTAGE

Rising of electric grid and local power plants become one of the reasons for construction FBG sensor for measuring high voltage. All measurements based on FBG can be chained together. Therefore, measurement unit price per sensor become cheaper and supports FBG sensor spread. FBG sensors and optical cables are made nonconductive and improve insulation of system from high voltage and can measure more than one physical quantity. Almost all measurement in power transmission and distribution network can be transduces into FBG sensing and monitored over tens of kilometers. High voltage measurement transforms mechanical strain from piezoelectric ceramic into mechanical stress and allow measure of voltage by FBG. Test configuration is described on Figure 3.

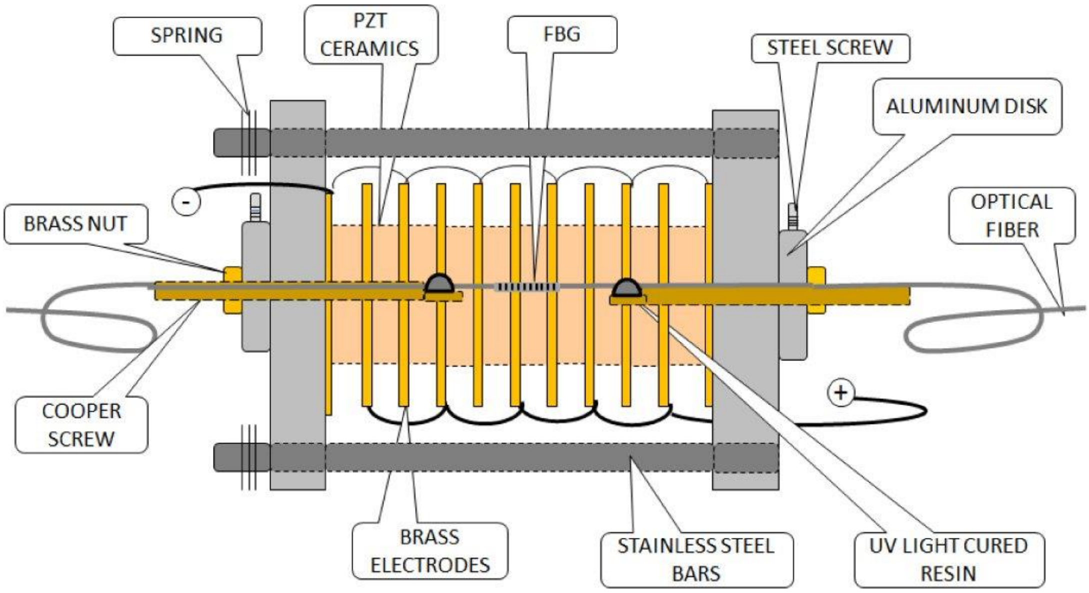

Figure 3: High voltage measurement based on electrostrictive material [10]

5 CURRENT MEASUREMENT

Similar principle with different material is used for current measurement sensors. These sensors are based on magnetostrictive materials and transforms current into mechanical stress. [11],[12]. This system provides great noise immunity, insulation between high voltage and ground and individual measuring elements. In opposite to bulk and heavy current transformers for measurement current there is lightweight magnetostrictive fiber probe with great insulation and ability to transmit measured signal tens kilometers far. Figure 4 describes behavior of FBG current sensor based on magnetostrictive material.

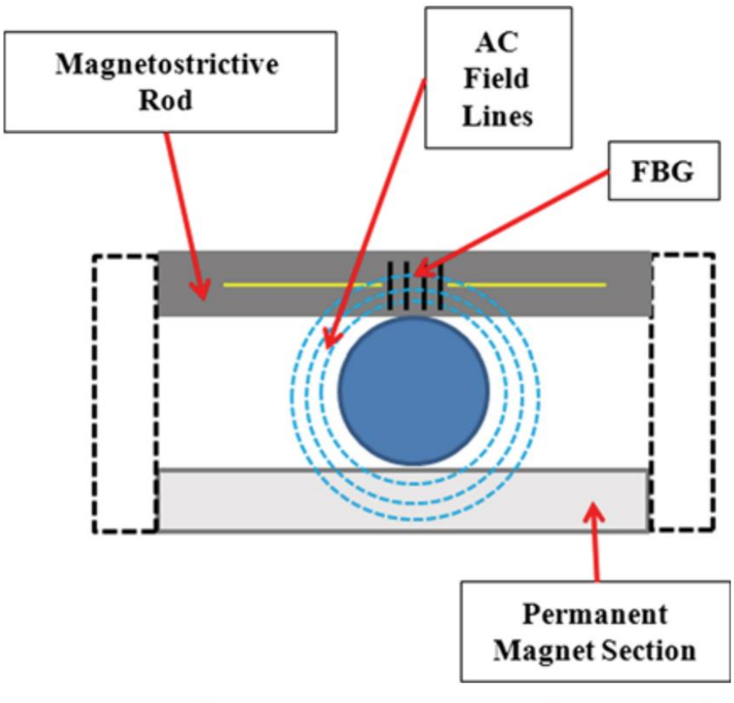

Figure 4: Current measurement sensor principle [11]

6 TILT AND INCLINOMETRIC SENSORS

Tilt and inclinometric measurement utilizes gravity force and weight bonded on end of the fiber. Tilt measurement uses one axial movement and fixture on another axis. There is single axis tilt sensor on Figure 5 right side. Sensor consist of fixture shown green, holding prestrained fiber with two FBGs. Yellow tube makes support for solid ball in the middle and takes over some strain in nonvertical positions of sensor. Due to combination of two FBGs, temperature dimension change impacts both and compensate temperature drift. Two axis inclinometers are designated same way, but there are 4 FBGs bonded in tetrahedrons corners. Dual axis inclinometer can measure roll and pitch angles without dependence on temperature drift. Complete principle is described in [13].

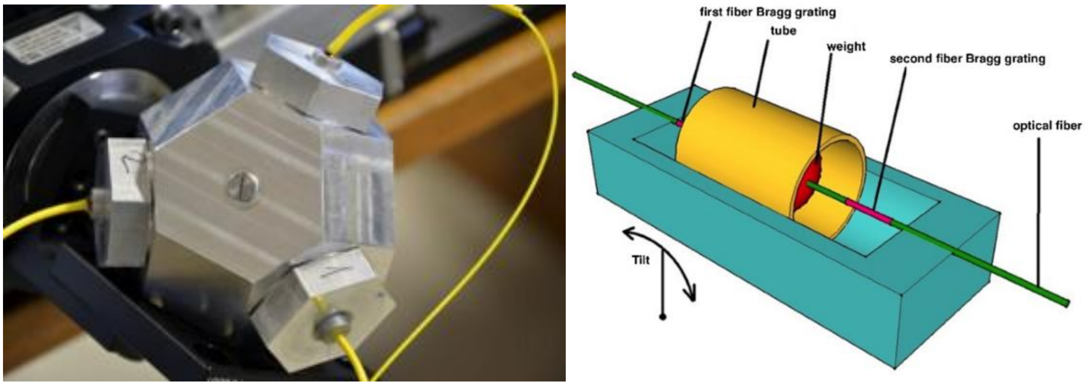

Figure 5: Inclinometer model and finall realization[13]

7 VIBRATION SENSOR

Next measurement feasible on FBG is vibration measurement. Sensor principle use tilted FBGs in combination with tapered section on fiber. Sensors are robust and can measure frequencies from 10 to 500 Hz. This type of sensor is commonly used for vibration measurements on bridge constructions, towers, concrete constructions and others.

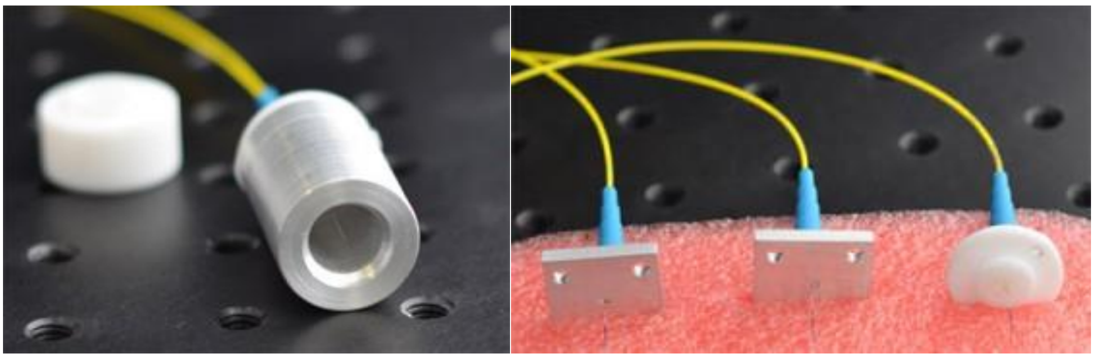

Figure 6: Vibration measurement sensors[8]

8 CONCLUSION

Different measurement methods with FBGs are presented in this paper. Novel approach to measure temperature, strain, voltage, current, inclination in same time on one fiber was presented. These chain multiplexing of sensors are so-called lab on fiber. Optical sensors are suitable for harsh environments like transmission and distribution networks. Another advantage of fiber sensing can be used for chemical and explosive industry like oil and gas or aircraft.

REFERENCES

[1] ZHENG, Binghui a Qilong KANG. A Novel Fiber Bragg Grating Sensor Analyzer Based on FPGA and DSP Platform. In: *2012 Fifth International Symposium on Computational Intelligence and Design*, ISBN 978-1-4673-2646-9

[2] BARON, Fabian E., German ALVAREZ-BOTERO, Francisco AMORTEGUI, Daniel PASTOR a Margarita VARON. Temperature measurements on overhead lines using fiber Bragg grating sensors. *2017 IEEE International Instrumentation and Measurement Technology Conference*. ISBN 978-1-5090-3596-0.

[3] SHRUTHI, S V a And S SUNDARAVADIVELU. HIGH TEMPERATURE MEASUREMENT USING FIBER BRAGG GRATING SENSOR. *Indian J.Sci.Res*. ISSN 2250-0138.

[4] LUPI, Carla, Ferdinando FELLI, Andrea BROTZU, Michele Arturo CAPONERO a Antonio PAOLOZZI. Improving FBG Sensor Sensitivity at Cryogenic Temperature by Metal Coating. *IEEE Sensors Journal*. ISSN 1530-437X.

[5] TSYBULNYK, S. O. a D. O. PIVTORAK. Method of determining the strain value from the output signal of the fiber optical sensor. *2017 IEEE First Ukraine Conference on Electrical and Computer Engineering (UKRCON)*. ISBN 978-1-5090-3006-4.

[6] KREUZER, Manfred. New horizons The optical measurement chain from HBM Strain Measurement with Fiber Bragg Grating Sensors.

[7] *Temperature Probe | os4200 - Micron Optics* [online]. [vid. 2018-03-15]. Dostupné z: http://www.micronoptics.com/product/temperature-probe-os4200/

[8] RADIM ŠIFTA. *Optické senzory | SFO* [online]. 2017 [vid. 2018-03-14]. Dostupné z: http://sfo.networkgroup.cz/cs/opticke-senzory/

[9] *Fiber Optics Sensing System: A New Technology for Measurement - YouTube* [online]. 2015 [vid. 2018-03-14]. Dostupné z: https://www.youtube.com/watch?v=_CdULw4-j_o

[10] RIBEIRO, Bessie A. a Marcelo M. WERNECK. A mechanical method to tuning a FBG-PZT voltage sensor. In: Hypolito J. KALINOWSKI, José Luís FABRIS a Wojtek J. BOCK. 2015 International Society for Optics and Photonics.

[11] WERNECK, Marcelo Martins, Regina Célia da Silva Barros ALLIL a Fábio Vieira Batista de NAZARÉ. *Fiber Bragg gratings : theory, fabrication, and applications*. ISBN 9781510613850.

[12] YAO, Yuan, Ciming ZHOU, Dongli WANG a Lin WU. Research on fiber Bragg grating huge current sensing based on electromagnetic force. 2011 International Society for Optics and Photonics.

[13] URBAN, František jr., Helán RADEK, František sr. URBAN, Lukáš KOČÍ a Josef ELIÁŠ. Bragg grating implementation of fibre optic inclinometer. 2017 *In Sensors and Electronic Instrumentation Advances: Proceedings of the 3rd International Conference on Sensors and Electronic Instrumentation Advances*.